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Micro Pirani Vacuum Gauges Manufactured by a Film Transfer Process

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Abstract

A low cost and low temperature transfer process of electroplated Ni microstructures is presented. The process is based on adhesion control of molded Ni microstructures on donor wafer by using plasma deposited fluorocarbon film. Low temperature adhesive bonding of the microstructures on the target wafer using BCB sealing enables mechanical tear out from the donor wafer. Interest of this process is demonstrated here in the case of micro pressure sensors based on the Pirani principle. Suspended Ni electroplated microwires of 0.55 to 1.2mm length, 10µm width and 700nm to 10µm thickness were characterized into pressure dependant chamber. These sensors exhibit good sensitivity in the range of 0.1 to 100mbar. The presented results thus demonstrate the interest of a simple film transfer process for elaboration of 3D microstructures.

Keywords: Pattern transfer ; Adhesion control ; Low temperature ; Adhesive bonding ; 3D microstrutures ; Vacuum Gauges ; MEMS

1. Introduction

Nowadays, micro and nano systems fabrication technologies should allow the integration of any passive or active materials (magnetic, piezoelectric, polymers,...) in various forms (films, micro/nanostructures,…) to build and/or package highly integrated multi-functional systems. A generic technology able to solve incompatibility issues related to the mixing of different technologies is pattern or device transfer by wafer bonding from a donor wafer to the target device wafer. Ideally such a process should be versatile (patterns made of any materials, of any shape and of any size, multiple transfers, any target surface type), low cost (high yield, one donor wafer for several transfers), selective and overall should involve minimum interaction and processing steps on the target wafer.

A general principle in film transfer processes is to use a sublayer [1] and/or a thermal/surface processing [2] to lower the adhesion of the film to be transferred. We investigate more precisely on the use of fluorocarbon polymer thin films as low adhesion sublayer. The principle of the proposed process (IEF & KFM Technology patent pending) is described in Sect. 2. Vacuum measurements of transferred Ni microPirani are exposed in Sect. 3.

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2. Film transfer process using fluorocarbon anti-adhesive layer

2.1. Principle

The proposed thin film MEMS process is based on the low temperature transfer of electroplated Ni microstructures from a donor Si wafer to the target wafer. It involves a reduced number of technological steps: donor wafer passivation and coating with an anti-adhesion C_xF_y layer (Fig. 1.1&2), molding of the Ni patterns (Fig. 1.3), alignment and low temperature adhesive bonding of the donor wafer on the target wafer (Fig. 1.6) and finally mechanical release of the donor wafer to leave the Ni film (Fig. 1.7). Note that this process could easily be converted to a die to wafer process by dicing the Ni patterns before flip chip bonding.

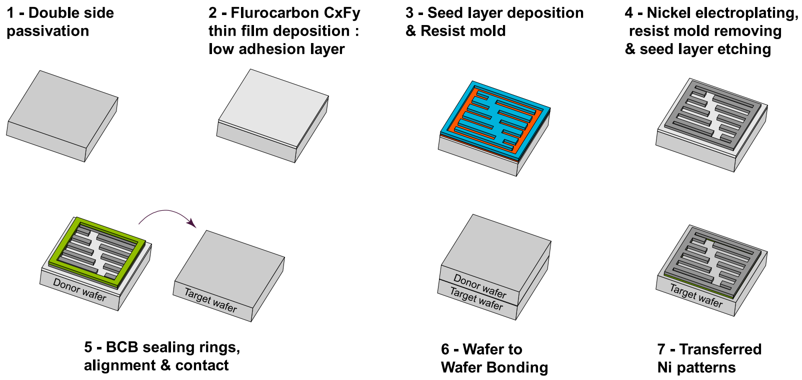


Fig. 1. Principle of the thin film transfer process investigated

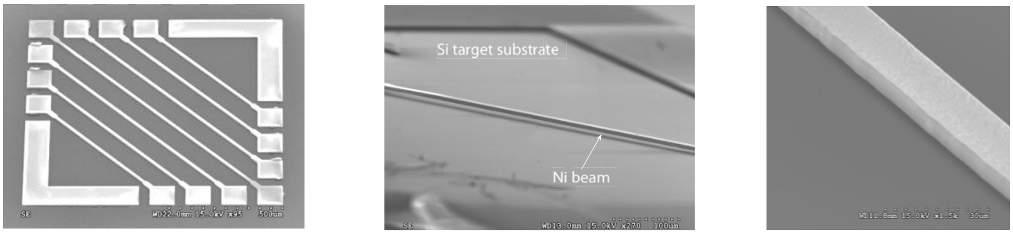
The proposed film transfer process clearly relies on a lower mechanical adhesion of the Ni film on the donor wafer than on the target wafer. We investigate more precisely on the use of fluorocarbon polymer thin films as low adhesion sublayers. Indeed, fluorocarbon polymers are well suited for this purpose as adhesion of materials on these materials is known to be weak without a specific surface processing and their melting point is relatively high in the 280 to 400°C temperature range [3]. Fluorocarbon film adhesion could be tuned by thermal annealing, by exposure to an N_2/H_2 plasma and/or by using a reactive metal sublayer like Titanium. Ni films are elaborated by nickel electroplating. This metallic material has a high Young's modulus (close to 200 GPa). In addition, electroplating provides conformal thick layers (up to a few tens of micrometer) at room temperature with a high deposition rate and a low residual stress according to deposit conditions. Moreover, Ni film can be easily patterned by growth through a thick resist mold so no etching is required after their growth. The wafer bonding temperature is limited by the thermal stability of the fluorocarbon layer and eventually by that of the environment present on the target wafer. In this paper we selected adhesive bonding with BCB (BenzoCycloButene) for the sealing of Ni film because it can be carried out at low temperature (250°C) and it is very tolerant to host wafer topography variations [4]. In summary, this process does no need any processing of the target wafer apart keeping some room for sealing rings and its interaction with the device wafer is limited to heating during the bonding step at low temperature (250°C). It should thus be compatible with a large range of micro and nanodevices including MEMS, CMOS integrated circuits and NEMS. Moreover the application of this process has already been demonstrated for MEMS thin film packaging [5].

2.2. Technological steps

Polished <100> wafers were used for the development of thin film transfer process. The first technological step is a DRIE etching of a few micrometers deep alignment marks on the back side of the carrier Si wafer which could be useful if alignment between the donor and the target substrates were needed. Then a 150nm thick wet thermal oxide was grown mainly to protect the back side of the substrate during the future nickel deposition. An anti-adhesion C_xF_y film is then deposited on the oxidized front Si surface by plasma polymerization (Fig. 2b). The measured water contact angle on as-deposited C_xF_y films is equal to 115°. This surface is thus hydrophobic. Next, a 10µm thick photoresist (AZ4562) was spin coated, UV exposed and developed to elaborate molds. The Ni film is then electroplated on a previously sputtered Cu (100nm) seed layer. Electroplating was performed in a classical Watt-type electrolytic bath based on a N_2SO_4, $NiCl_2$ and H_3BO_3 mixture in which saccharine was added as an inhibiting growth reagent to control grains sizes. Ni electroplating set-up was optimized previously [5].Consequently for the fabrication of Ni patterns, a low current density (11mA/cm^2) was selected in order to limit the edge effect and molecular hydrogen formation to get a low surface roughness (<10nm). From 7µm down to 700nm thick Ni film could be obtained with appropriate electroplating time. After resist mold removal, the following step is an etching during a few seconds of the copper seed layer remaining between the Ni patterns with a commercial etchant having a high Cu etching selectivity with respect to Ni. Next, a photosensitive BCB film was spin coated on the surface and patterned to get sealing rings. A BCB sealing ring thickness (4.5µm) was chosen to obtain a good tolerance to surface topography variations after bonding. The fabricated sealing rings exhibit a width in the 50–200µm range. Adhesive bonding of the donor and the target wafers was performed with an EVG501 double side aligner. After double-side alignment the wafers were bonded under vacuum with a force of 3500N and following the thermal annealing optimized previously in [6].

The final step of the transfer process is the release of the carrier wafer to leave the patterned Ni film on the target wafer. This was done manually by wedge lift-off. . The proposed process has allowed us to manufacture 7µm, 3µm and 700nm thick double-clamped nickel microbeams that can be employed as highly sensitive micro Pirani gauge. Fig. 3 shows a typical SEM picture of a transferred microPirani gauge on a host Si wafer. Owing to the good anti-adhesion properties of the C_xF_y layer a high final yield could be obtained: closed to 90%. Note that this final yield also includes Ni pattern failures during other fabrication steps, notably during electroplating.

3D profiles of double-clamped nickel microbeams measured by White Light Interferometry by the way of a Zoomsurf 3D system from Fogale Nanotech Company shows good conformity of Ni films. Low deflexion of suspended Ni beams was observed. Especially 1.2mm length, 10µm width and 700nm free-standing beams are deflected with bow lower than 300nm at the center. The Ni film top surface microroughness is about 10nm. The gap (Fig. 3(c)) between free stand Ni beams and Si target substrate directly relies on BCB sealing ring thickness after bonding witch can be lower that initial BCB thickness prior to bonding. Due to BCB viscous state during bonding and high bonding force, the BCB sealing rings thickness tends to be lowered. However, the gap could be accurately determined by comparison of 3D profiles of the microbeams before and after transfer.



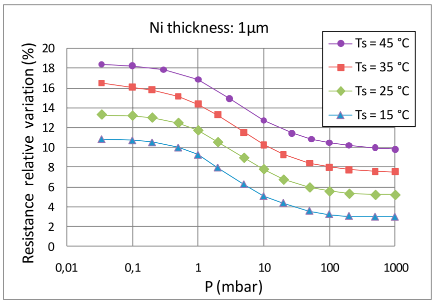
(a) (b) (c)

Fig. 3. SEM pictures of transferred microPirani gauge (a) and a free-standing nickel microbeam (b,c)

3. Characterization of the micro pirani vacuum sensors

Nickel microPirani gauges of various length and thickness have been characterized as pressure sensors into pressure dependent chamber in the range of 3.10^{-2}mbar to atmospheric pressure. Temperature of the substrate was controlled using thermoelectric Peltier cell. Fig. 4 (a) shows characteristics of a 1220µm long, 10µm wide and 1µm thick microwire heated by constant electrical current of 5mA. The air gap between the microwire and the substrate was 3µm. Good sensitivity was obtained in the range of 0.1 to 100mbar, with nearly 8% variation of electrical resistance. Dependency of the sensor response with the substrate temperature T_S was also clearly observed [7,8]. Results on a 7µm thick microPirani presented on Fig. 4 (b) show similar behavior. This microwire is thicker than the previous one, so higher value of the heating current (35mA) is necessary to get similar sensitivity to pressure variations [8].

These measurements confirm the interest of the proposed transfer process for manufacturing of 3D microdevices such as microPirani vacuum gauges.



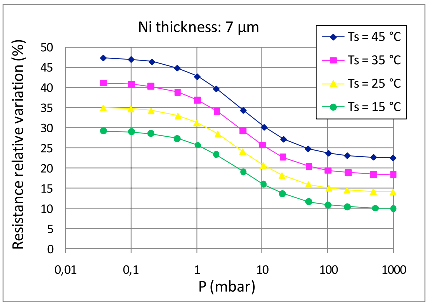


Fig. 4. Vacuum characteristics of 1220 µm length micro beams: (a) 1 µm Ni thickness, I = 5 mA; (b) 7 µm Ni thickness, I = 35 mA.

4. Conclusion

A new film transfer process based technology has been investigated. It allowed us to successfully realize high sensitivity microPirani gauges. This process is very promising for various applications and brings new perspectives towards 3D integration of MEMS/NEMS.

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References

[1] Kawata H, Ryugou K, Ohta S, Yasuda M, Hirai Y. Fabrication of Cantilevers by two-Step Transfer Process without lithography, *Jap. J. Appl. Phys.* 2009;**48**.

[2] Onoe H, Nakai A, Iwase E, Matsumoto K, Shimoyama I. Temperature-controlled transfer and self-wiring for multi-color light-emitting diode arrays, *J. Micromech. Microeng.* 2009;**19**.

[3] Taberham A, Kraft M, Mowlem M, Morgan H. Fabrication of lab-on-chip devices from fluoropolymers, *J. Micromech. Microeng.* 2008; **18**.

[4 Jourdain A, De Moor P, Baert K, DeWolf I, Tilmans HAC. Mechanical and electrical characterization of BCB as a bond and seal material for cavities housing (RF-) MEMS devices, *J. Micromech. Microeng.* 2005;**15**;89–90.

[5] Brault S, Garel O, Schelcher G, Isac N, Parrain F, Bosseboeuf A, Vergus F, Desgeorges M, Dufour-Gergam E. MEMS packaging process by film transfer using an anti-adhesive layer, *Microsyst. Technol.* 2010; **16** ; 1277-1284.

[6] Brault S, Leroux X, El-Amrani M, Dufour-Gergam E, Parrain F,Verjus F, Schwindenhammer P, Lani S, Bosseboeuf A. BCB wafer bonding technologies for wafer-level packaging with an integrated MEMS resonator. 2006;*In: Conference IMAPS, San Diego*.

[7] Zhang FT, Tanga Z, Yua J, Jin RC. A micro-Pirani vacuum gauge based on micro-hotplate technology. *Sensors and Actuators A: Physical* 2006;**126**;300–5.

[8] Pons N, Mailly F, Latorre L, Martincic M, Verjus F, Pellet C et al. Pressure sensor for smart wafer-level packaging of MEMS, *Proc. Eurosensors* 2008;**1**;408–12.